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Alien algae *Undaria pinnatifida* causes habitat loss for rocky reef fishes in north Patagonia

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Abstract Since the introduction of *Undaria* into Nuevo Gulf, Argentina, around 1992, this alien seaweed has now colonized different sites over 700 km of coast, forming dense seasonal forests in waters from 0 to 15 meters in depth. In the spring it is common for plants of *Undaria* to break away from the substrate and be transported by sea currents. As *Undaria* gets stuck onto reefs it has the potential to reduce habitat quality for reef fish by physically obstructing refuges. This study aims to assess the impact of *Undaria* on the abundance of four species of rocky-reef fishes by an observational experiment. Fish abundance on reefs with and without *Undaria* was estimated by underwater visual census methods. Sites were classified according to their topographical relief, as this was expected to influence the effect of *Undaria* on the abundance of reef fishes. Fish abundance decreased markedly in low-relief reefs that had been covered by *Undaria*. In contrast, the drifting *Undaria* had no effect on the abundance of any of the fish species considered in high-relief reefs, where it tends to cover only the lowest-lying areas, leaving much of the refuges for fish unaffected. In conclusion, the presence of *Undaria* off the coast of Argentina results in transitory habitat loss for reef fishes inhabiting low-relief reefs during late spring and early summer. Although we do not know how much of a threat this habitat loss represents for the conservation of reef fish populations of northern Patagonia, the documented local impact of *Undaria* within the gulfs is strong and may affect a number of recreational and commercial activities which are centered on the reefs and their fish assemblages.

Keywords Alien algae · *Undaria* · Temperate reef fishes · Habitat loss · Patagonia

Introduction

The impact of invasive species on native marine communities has been a source of increasing concern for scientists, governments and conservationists worldwide (Carlton 1996; Carlton and Geller 1993; Ruiz et al. 2000). At present 31 exotic species have been documented to become established in the coastal waters of Argentina (Orensanz et al. 2002). Of these species, the introduction of the alga *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) represents a particularly notorious phenomena due its conspicuousness, potential effects on coastal systems and interference with human activities like diving and angling (Orensanz et al. 2002; Piriz and Casas 1994). *Undaria*, which reaches a length of up to 2 m, is native

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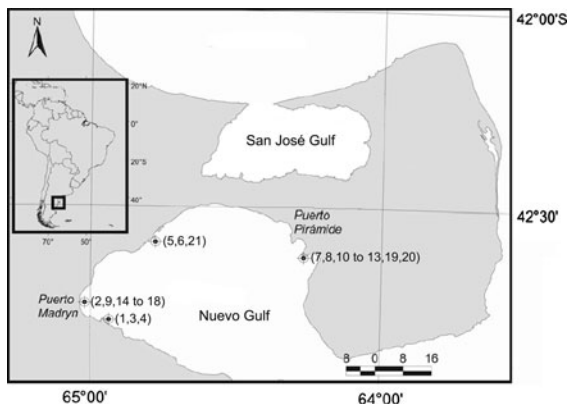e-mail: alejo@cenpat.edu.ar

Fig. 1 *Left* South America. *Right* Valdes Peninsula. Censused reefs are numbered from 1 to 21; circles indicate four areas were reefs are distributed

of northeast Asia (Japan, Korea and China) (Akiyama and Kurogi 1982). In 1971 it was found in l'Etang de Thau in France and has since spread throughout the Mediterranean coasts as well as other temperate waters around the world, mainly as a result of shipping (Curiel et al. 1994; Fletcher and Manfredi 1995; Hay 1990; Salinas et al. 1996; Stegenga 1999). In Argentina it was first registered in Puerto Madryn in 1992, and since then it has spread all over the Nuevo Gulf, expanding 700 km to the south (Fig. 1). Recently *Undaria* has also bypassed the natural geographical barrier represented by Peninsula Valdes and is now expanding northward, having reached as far as San Jose Gulf (Fig. 1) (Martin and Bastida 2008).

Although there is a potential economic value to *Undaria* both as a food source and to the pharmaceutical industry, its expansion into the northern Patagonian gulfs and Peninsula Valdes, a UNESCO Natural Heritage Site, may threaten eco-tourism activities that depend on local biodiversity and the esthetic quality of the ecosystem. In particular, a variety of recreational activities have been conducted historically in the gulfs, including diving, angling and spear fishing, typically concentrated on rocky reefs and their associated fish assemblages. Although the visual impact of *Undaria* on the reefs is already a serious concern for tourist operators and amateurs, to date there is no direct evidence of negative impacts of *Undaria* on the native flora or fauna. Here we postulate that because reef fish are strongly dependent on the shelter provided by crevices and holes within the rocks (Galván 2008),

they may be negatively impacted by accumulation of drifting *Undaria* on the reefs.

With the exception of a few seasonal patches of *Macrocystis pyrifera* (Laminariales, Phaeophyceae) (Eyras and Boraso 1994) forests, most native species of macroalgae associated with northern Patagonian rocky reefs (e. g. *Codium* spp*., Dictyota* sp*.* and *Ulva* spp*.*) rarely exceed a few centimetres in height. In contrast, *Undaria* produces dense seasonal forests on rocky bottoms between 0 and 15 meters in depth. Young *Undaria* sporophytes recruit in winter and subsequently grow rapidly to form dense forests by spring and early summer. Fronds start to decompose in late spring, and their size and weight decrease progressively until mid-autumn when reefs become free of algae (Casas et al. 2008). During late spring and early summer many large plants detach from the substrate and drift with the currents. These drifting individuals stuck in rocky reefs' holes and crevices as well as in other irregularities of the sea floor.

In this study we investigate the potential impact of drifting *Undaria* on the fish assemblages caused by the obstruction and loss of crevices and holes that provide refuge to many reef fishes. To this end we tested two hypotheses: H1) the abundance of reef fish decreases in the presence of drifting *Undaria*, which reduce the availability of refuges; H2) the impact of drifting *Undaria* on fish abundance is greater in low-relief than in high-relief reefs. A smaller effect was expected in high-relief reefs because the drifting algae tend to accumulate on the lowest-lying areas of high reefs, leaving much of the rocky refuges used by fish clear of algal obstructions.

Materials and methods

Study site

The study was conducted on 21 shallow (<20 m deep) reefs from Nuevo Gulf (Fig. 1). Reefs are formed by isolated small rocky outcrops that extend no longer than a few hundred metres on otherwise flat bottoms. Most commonly, these reefs are linear structures, typically breaks or ledges (of up to 4 m high) formed along the edge of submerged limestone platforms. Crumbled portions of the ledges determine both the width and structural complexity of these reefs (Fig. 2).
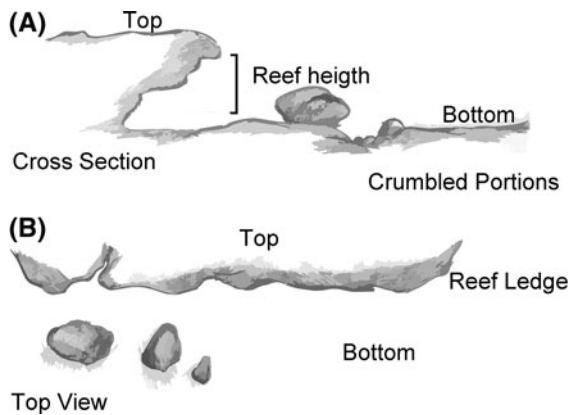
Fig. 2 Diagram representing the most common structure of Patagonian reefs, showing both a *cross section* and a *top view*

We classified reefs according to their height (i.e. the elevation of the break above the sea bottom) which determines the size of the refuges (see cross view in Fig. 2). Reefs with break heights lower than 50 cm were considered "low-relief reefs" and reefs with heights higher than 50 cm were considered "high-relief reefs".

Characteristics of Patagonian reef fish assemblages

The fish assemblages of northern Patagonia rocky reefs are characteristically of low diversity, containing no more than 19 species belonging to 15 families, although only 11 of these are common (Galván et al. 2009). Here, we only considered the most common non-cryptic species, i.e. conspicuous species easily detectable by standard visual census techniques. This group includes *Pinguipes brasilianus* Cuvier, 1829 (Percodei, Pinguipedidae), *Pseudopercis semifasciata* (Cuvier, 1829) (Percodei, Pinguipedidae), *Sebastes oculatus* Cuvier, 1833 (Percodei, Sebastidae) and *Acanthistius patachonicus* (Gill, 1862) (Percodei, *Insertae Sedis*) (Irigoyen et al. 2008).

Fish abundance in shallow reefs fluctuates seasonally. Highest abundances of all four fish species occur during early autumn, after which abundance diminishes reaching a minimum towards the end of winter and increasing again gradually during spring and early summer (Galván 2008). While *Pagrus pagrus* Linné 1758 (Percodei, Sparidae) and *Nemadactylus bergi* (Norman, 1937) (Percodei, Cheilodactylidae) are conspicuous species, both are virtually absent from the reefs during winter and spring, thus were not included in this analysis (see below). Seasonal patterns of fish abundance are in phase with water temperature variation, which ranges from to 8–9°C during late winter to 17–18°C in early autumn.

Sampling design and data analysis

A total of 21 reefs were selected on the basis of two treatments: (1) reef relief as described above (two levels: low and high); (2) *Undaria* presence (two levels: low/absent and high density) (Table 1). For treatment 2, *Undaria* was considered to be at high density when a forest was formed during spring and early summer covering at least 80% of the reef area. *Undaria* densities were classified as low/absent when less than three individuals were present in the segment of reef censused. Intermediate densities of *Undaria* between these two extremes were not encountered.

Fish abundance on each reef was counted on two occasions: (1) during late winter (August/September of 2007) when fish abundance is at a minimum and there are no drifting plants of *Undaria* and (2) during late spring-early summer (December of 2007) when fish abundance is intermediate and the reef bottoms are covered by drifting plants of *Undaria*.

Fish counts were undertaken on each of 21 reefs using standard visual census methods (Brock 1954) along one fixed permanent 25-m transect. Transects were randomly positioned along the total length of the reef ledge and delimited by iron pickets driven permanently into the bottom. In two cases (reefs 19 and 20), reefs were shorter than 25 m and so all fish observed on the entire reef were recorded. On each census occasion, abundances of the four species, *A. patachonicus*, *S. oculatus*, *P. brasilianus* and *P. semifasciata*, were counted sequentially over four consecutive passes made by the diver following the same species order. Only the specimens bigger than 10 cm were counted. Different passes for each species were done in order to improve the accuracy of the census. While the use of successive passes could affect abundance of mobile species, previous studies conducted on the northern Patagonian reefs (Venerus et al. 2008) and on other temperate reefs (De Girolamo and Mazzoldi 2001) using multiple passes by a diver found no effect attributable to diver disturbance. This is because sedentary species remain close to refuges despite diver disturbance.

Table 1 Late-spring and late-winter counts of fishes observed on the censused reefs and their differences (Deltas). Counts are by species and for all species combined

Reef type	Reef	Species	Late spring–early summer (n)	Late winter (n)	Difference
Low relief—With Undaria	8	A. patachonicus	30	16	−14
		S. oculatus	27	11	−16
		P. brasilianus	9	6	−3
		P. semifasciata	9	7	−2
		Total	75	40	−35
	9	A. patachonicus	8	3	−5
		S. oculatus	4	2	−2
		P. brasilianus	3	1	−2
		P. semifasciata	2	0	−2
		Total	17	6	−11
	12	A. patachonicus	14	4	−10
		S. oculatus	3	4	1
		P. brasilianus	0	3	3
		P. semifasciata	3	1	−2
		Total	20	12	−8
	13	A. patachonicus	4	0	−4
		P. semifasciata	3	0	−3
		Total	7	0	−7
Low relief—Without Undaria	19	A. patachonicus	0	4	4
		S. oculatus	0	1	1
		P. brasilianus	0	3	3
		Total	0	8	8
	11	A. patachonicus	3	7	4
		S. oculatus	0	3	3
		P. brasilianus	0	5	5
		Total	3	15	12
	28	A. patachonicus	16	13	−3
		S. oculatus	4	6	2
		P. brasilianus	1	2	1
		P. semifasciata	9	14	5
		Total	30	35	5
	10	A. patachonicus	70	78	8
		S. oculatus	16	16	0
		P. brasilianus	8	7	−1
		P. semifasciata	1	1	0
		Total	95	102	7
	20	A. patachonicus	25	35	10
		S. oculatus	8	9	1
		P. brasilianus	2	5	3
		P. semifasciata	0	1	1
		Total	35	50	15
High relief—Without Undaria	14	A. patachonicus	15	24	9
		S. oculatus	8	8	0
		P. brasilianus	3	18	15
		Total	26	50	24

Table 1 continued

Reef type	Reef	Species	Late spring–early summer (n)	Late winter (n)	Difference
	17	A. patachonicus	0	6	6
		P. brasilianus	1	4	3
		Total	1	10	9
	18	A. patachonicus	4	15	11
		P. brasilianus	0	4	4
		Total	4	19	15
	26	A. patachonicus	11	8	−3
		S. oculatus	0	3	3
		P. brasilianus	1	8	7
		Total	12	19	7
	27	A. patachonicus	14	11	−3
		S. oculatus	3	3	0
		P. brasilianus	1	5	4
		Total	18	19	1
High relief—With Undaria	15	A. patachonicus	14	23	9
		S. oculatus	5	6	1
		P. brasilianus	1	10	9
		Total	20	39	19
	16	A. patachonicus	16	33	17
		S. oculatus	2	3	1
		P. brasilianus	1	1	0
		Total	19	37	18
	21	A. patachonicus	11	12	1
		S. oculatus	2	3	1
		P. brasilianus	3	4	1
		Total	16	19	3
	22	A. patachonicus	6	13	7
		S. oculatus	0	4	4
		P. brasilianus	1	4	3
		Total	7	21	14
	23	A. patachonicus	8	10	2
		S. oculatus	2	2	0
		P. brasilianus	3	5	2
		Total	13	17	4
	24	A. patachonicus	11	22	11
		S. oculatus	2	2	0
		P. brasilianus	1	1	0
		Total	14	25	11
	25	A. patachonicus	16	15	−1
		S. oculatus	1	4	3
		P. brasilianus	0	1	1
		Total	17	20	3

The linear nature of the reefs plus good visibility always allowed censusing the entire width of the reefs following the procedure described above. Also, during the late spring-early summer census, the reefs, caves and crevices were inspected using artificial light, and drifting *Undaria* were pulled aside from caves in order to ensure that low abundances where not the result of *Undaria* simply hiding the fish.

Differences between the late spring-early summer and winter counts for each species were defined as:

$$\text{Delta} = \text{Ln (late spring} - \text{early summer count} + 1)$$
$$- \text{Ln (late winter count} + 1).$$

Reefs that had zero counts on both sampling occasions were excluded from the analyses. Linear models were fitted with the R software (R Development Core Team 2007) using relief and *Undaria* as fixed factors, and an interaction term relief × *Undaria*.

Results

Linear models showed highly significant differences between low reefs colonized by *Undaria* and the other three combinations of factors for *A. patachonicus, P. semifasciata* and the total number of fishes ($t_{3,17} = 3.6$, $P < 0.01; t_{3,17} = 6.08, P < 0.001$ and $t_{3,17} = 4.2, P < 0.001$, respectively), marginally significant in the case of *S. oculatus* ($t_{3,17} = 2.05, P = 0.056$) and not significant for *P. brasilianus* ($t_{3,17} = 1.6, P = 0.11$). In the case of *P. semifasciata* comparisons were only possible for low reefs (with two levels of *Undaria*) because this species is absent from high-relief reefs. Delta averages were negative for all species of fish in low-relief reefs that had been colonized by *Undaria* (Fig. 3). Negative values of "Delta" mean that lower fish counts were recorded in late spring-early summer than in late winter, contrary to the normal seasonal fluctuation in abundance observed in the absence of *Undaria* (Galván 2008). In sum, all species increased in abundance from late winter to late spring-early summer, with the exception of fish inhabiting low-relief reefs colonized by *Undaria*.

Discussion

Our results show that *Undaria* is associated with reduced abundance of fishes in low-relief reefs. We suggest that this reduction is the result of the seaweed physically obstructing access to shelters and so reducing the overall quality of the reef for fish populations. This effect was statistically significant for *A. patachonicus, S. oculatus, P. semifasciata* and for the total abundance of all species combined. The abundance of *P. brasilianus* also decreased where *Undaria* was present but the difference was not
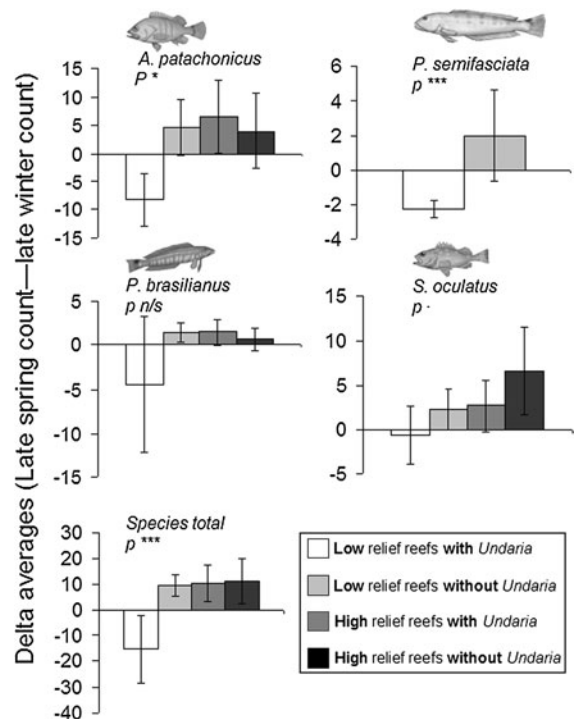

Fig. 3 Delta averages (± SD) between late-spring and late-winter counts of each species and of all species combined. *White bars* represent low-relief reefs with *Undaria*, soft grey represent low-relief reefs without *Undaria*, *gray bars* represent high-relief reefs with *Undaria* and *black bars* represent high-relief reefs without *Undaria*. Significance of the differences between low-relief reefs with *Undaria* and all the other combinations of factors is indicated by: • marginally significant, * significant, *** highly significant and n/s no significant ($P_{\alpha=0.05}$)

statistically significant (Fig. 3). Lack of significance for *P. brasilianus* may be due in part to the low overall abundance of this species within the study sites resulting in high levels of between-treatment variation (McClanahan et al. 2007).

In contrast to the negative effect of *Undaria* on low-relief reefs, the abundance of fish in high-relief reefs did not decrease in response to the presence of *Undaria*. We attribute this lack of effect to the fact that the drifting *Undaria* accumulate in low-lying areas of the reefs, while a large proportion of rocky refuges used by fish remains clear of algal obstruction.

A negative effect of drifting *Undaria* on reef fish such as observed in this study has not been reported for other regions of the world. Probably it occurs in Nuevo Gulf due to the fact that hard bottoms are constituted mainly by limestone platforms which favor *Undaria* breaking away. Although the total

volume of drifting *Undaria* is unknown, we estimated (Irigoyen, Unpublished data) that on average 60% of the *Undaria* individuals that recruited during the winter period become dislodged from the sea bottom by late spring and drift on local currents.

The net effect that drifting *Undaria* will have on reef fish populations depends on the costs incurred by fish forced to abandon the reefs, including increased predation risk and direct energy expenditure. Even if some fish do relocate to high-relief reefs or to deeper reefs unaffected by *Undaria,* the availability of such alternative habitats is likely to be limited. The proportion of low-relief reefs vs. high-relief reef is unknown and is likely to be a key factor in determining the impact of *Undaria* on the population sizes of reef fish. In the case of *P. semifasciata*, which is principally associated with low-relief reefs (Galván 2008), the choice of alternative reefs will be limited to those sites where local currents do not result in the accumulation of *Undaria,* probably in areas deeper than 20 m and distant from *Undaria* forests. For this reason *P. semifasciata* is likely to be particularly sensitive to the impact of this invasive seaweed. This species, the largest (up to 1.5 m in length and up to 30 kg) of the reef fishes, is targeted by recreational anglers and commercial fishers, and is also a charismatic component of the reef-fish assemblage, a fact of importance for recreational divers (Venerus et al. 2008). As such, reductions in its abundance on the coastal reefs could have an important economic impact.

In addition to these negative effects, *Undaria* could potentially affect the availability of prey items for reef fishes. As the presence of *Undaria* increases local habitat complexity and available substrata for benthic fauna, it is likely to augment prey abundance for at least some species. The assessment of such complex interactive effects are, however, beyond the scope of the present study.

Our study excluded fish species that are too rare for practical monitoring using common census techniques. We may speculate about the impact of *Undaria* on those species based on their ecological traits. There are three pelagic species observed occasionally on the reefs: *Diplodus argenteus, Nemadactylus bergui* and *Pagrus pagrus* (Galván 2008). Because they have a weak dependence on the shelter provided by crevices and holes, and they are more common in high-relief reefs (Galván 2008), they will probably be largely unaffected by *Undaria*. For small

cryptic species (<10 cm), caves and crevices at the scale of a few centimetres are likely to be key refuges. Such small crevices are not obstructed by drifting *Undaria* plants, which therefore are unlikely to negatively impact their abundance. On the contrary, it is possible that the increased habitat complexity associated with *Undaria* could create new small refuges reducing the impact of top-down population control of these species. Finally, *Bovichtus argentinus* and *Congiopodus peruvianus*, both cryptic species with a strong dependence on small refuges likely to be blocked by drifting *Undaria*, will probably be negatively affected.

Conclusion

There is a surprising lack of information on the impact of *Undaria* invasions on native communities (Underwood 1997; Wotton et al. 2004). The data presented here represent one of the first empirical demonstrations of the impacts of this alien macroalgae on reef fish populations. *Undaria* has a systematic, although temporally, effect on habitat availability for reef fishes inhabiting low-relief reefs. Although we do not know how much of a threat this habitat loss represents for the conservation of reef fish populations of northern Patagonia, the documented local impact of *Undaria* within the gulfs is strong and may affect a number of recreational and commercial activities which are centered on the reefs and their fish assemblages.

At present the control of *Undaria* populations has been largely ineffective worldwide and, in particular, restoration efforts based on algal removal have proved to be unsuccessful (Hewitt et al. 2005). Given the expense and potential for collateral damage to reefs by such cleaning, the viability of such an approach is doubtful, and at best is likely to be suitable only for areas of particular scientific or recreational value. It is also possible that low-relief reefs could be augmented by the creation of artificial reefs that would provide new refuges for some fish species, principally *P. semifasciata*.

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